Chapter 6

Concrete as a Building Material

CONCRETE AS A BUILDING MATERIAL

1. FUNDAMENTALS OF CONCRETE

1.1 Definition of Concrete

Concrete is basically a mixture of two parts: mineral aggregates and cement paste.

The paste (cement + water) binds the aggregates (sand + gravel or crushed rock) forming a rocklike mass after hardening as a result of the chemical reaction of cement and water (called hydration).

In a properly proportioned, well mixed and placed concrete, each aggregate particle is completely coated with paste. In a good concrete the paste not only coats the surface of the particles, but completely fills the space between the aggregate particles.

Sometimes, materials other than cement, water and aggregates are added (in small quantities) to the concrete during mixing in order to modify one or several properties in the fresh or hardened state. These materials are called admixtures.

The characteristics, performance and serviceability of concrete are a function of the physical and chemical properties of the ingredients, the manner in which they are proportioned and how they interact with each other. Properties of each of the mixture ingredients are therefore significant to the quality of the finished product.

1.2 Constituents

1.2.1 Cement

Cement is a „hydraulic" binder because it reacts with water in air or under water to form a hard, strong mass. By this reaction heat is evolved. A number of calcium silicates, calcium aluminates and related compounds are able to react in this way, and are the active components of commercial hydraulic cements.

1.2.2 Aggregates

Aggregates are generally divided into two groups: fine and coarse. Fine aggregates consist of natural or manufactured sand with particle sizes up to 5 mm. Coarse aggregates are those with particles larger than 5 mm. The maximum admissible grain size of the coarse aggregate in concrete depends usually upon the building process and design of the structural parts of the concrete construction. In most countries the maximum grain size of the aggregate for reinforced concrete ranges from 25 to 40 mm.

Since aggregates make up about 60 to 75% of the concrete volume, their selection is important. Aggregates should consist of particles with adequate strength and resistance to exposure conditions and should not contain materials that will cause deterioration of the concrete. A continuous gradation of particle sizes is desired for efficient use of the cement paste. In this text, it is assumed that suitable aggregates are being used.

A concrete that contains only fine aggregates (sand) with a particle size of up to 5 mm is called mortar.

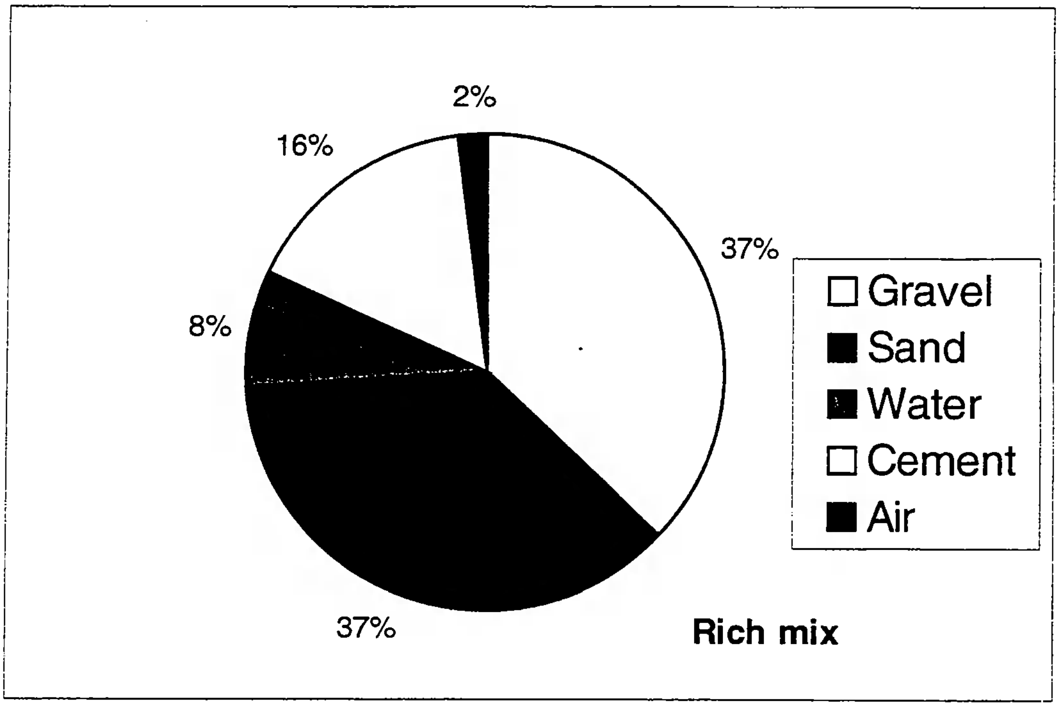
1.2.3 Water

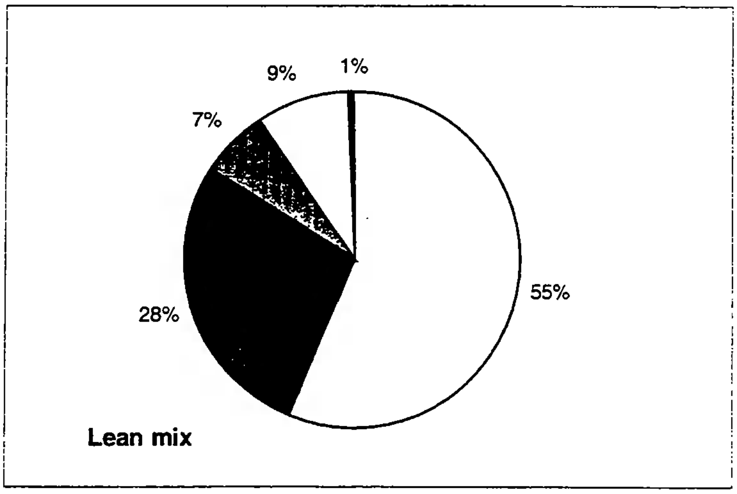
Water has two functions in the concrete mixture: first, it is essential for the hydration process of the cement; second, it converts cement into a paste and thus acts as lubricant making the concrete workable.

1.2.4 Cement Paste

Cement paste (the mix of cement and water) ordinarily constitutes about 15 to 27% of the total weight of concrete (Fig. 1). The quality of the concrete depends to a great extent upon the quality of the paste.

Fig. 1 Proportions of Concrete Constituent Materials (by weight)





1.3 Proportions

The proportions of the constituents in concrete can be varied in a certain range. A mix with a cement content below 10% is called lean mix (see Fig. 1 above).

1.3.1 Water/Cement Ratio

Most desirable properties of fresh and hardened concrete are influenced by the water/cement ratio, i.e. the ratio of the amount of water to the amount of cement used in the mix. This relationship is expressed in terms of the ratio of the weight of water (w) to the weight of cement (c):

$$\frac{w\ (kg)}{c\ (kg)} = w\,/\,c \text{ ratio}$$

The less water is used (lower w/c ratio), the better the quality of the hardened concrete - provided that it can be mixed and compacted properly. Some of the advantages of reducing the w/c ratio are:

- Increased compressive and flexural strength
- Increased watertightness, lower porosity
- Better bond between concrete and reinforcement
- Less volume change due to wetting and drying (drying shrinkage)
- Increased resistance to weathering (better durability)
- Lower water absorption capacity

2. PROPERTIES OF CONCRETE

The properties of concrete depend very much on the concrete age. Roughly three stages can be distinguished:

<u>fresh concrete</u> workable mass ↓ intermediate stages (sometimes called „green“ and „young“ concrete) ↓ <u>hardened concrete</u> artificial stone which has reached the properties required for a specific construction

The transition from fresh to hardened concrete is a continuous process during which the hydration of cement paste takes place.

Probably the five most important potential properties of concrete are:

- Workability
- Durability
- Resistance to compressive stress (compressive strength)
- Ability to protect reinforced steel against corrosion
- Versatility

The first property, the workability, allows the fresh concrete to be placed and compacted into forms of any reasonable shape; the durability, ensures a long life for the hardened mass, the third, fourth and fifth property form the basis of modern designs combining the compressive strength of concrete with the tensile strength of steel.

2.1 Properties of Fresh Concrete

2.1.1 Workability and Consistency

The term workability describes the ease of handling, placing and finishing fresh or „plastic" concrete. Although subjective by definition, workability has a profound effect on placement, pumpability, segregation and bleeding of the concrete mixture and, therefore, directly influences economy, strength and durability of the hardened concrete. Workability encompasses a large number of fresh concrete properties. Usually, only one, namely consistency, is measured and the results are used as indication of the workability.

Consistency expresses the ability of the fresh concrete to flow. The mix must be of such a consistency that it will e.g. flow and fill spaces around reinforcing steel or can be pumped. If concrete has the right consistency, it will not crumble or become too stiff to be workable but will flow firmly. For uniform consistency and good workability, the concrete should be as homogeneous as possible.

The use of suitable chemical admixtures called plasticizers or water reducers can help modify the flow properties of concrete and lead to improved plasticity and flowability at the same W/C ratio or to reduced W/C ratio to obtain the same workability.

2.1.2 Consolidation

Vibration sets into motion the particles in the fresh concrete, reducing friction between them, and giving the mixture the mobile qualities of a thick fluid. Mechanical vibration permits use of a stiff mixture with a lower water content.

2.1.3 Unit Weight

Concrete that is normally used in pavements, buildings, and other structures has a unit weight in the range of 2200 to 2400 kg/m^3. The unit weight of concrete varies, depending on the relative density of the aggregate, the amount of air that is entrapped or purposely entrained, and the water and cement contents.

2.2 Properties of Hardened Concrete

2.2.1 Strength

Compressive strength, i.e. resistance to compressive stresses, is certainly a primary characteristic of a good concrete on which the design of most structures (e.g. buildings, bridges, silos, tunnels, etc.) is based. Flexural or beam strength of concrete is essential for highway and airport pavements.

The strength of concrete is most often measured and specified on the basis of compressive strength. Principal factors affecting the compressive (as well as flexural and tensile) strength are type and size of the aggregate as well as the contents of cement and water in the mixture. The strength generally increases as the water/cement ratio is decreased. With time the strength continues to increase as long as unhydrated cement is present, provided that the concrete remains saturated with water.

2.2.2 Volume Changes

Hardened concrete changes volume slightly due to changes in temperature, moisture content and sustained stress. These volume or length changes may range from about 0.01 to 0.08%. Thermal volume changes of hardened concrete are approximately the same as those of steel.

Concrete kept continually moist will expand slightly. When permitted to dry, concrete will shrink. The shrinkage depends upon several factors such as amounts of mixing water and aggregate, properties of the aggregate, size of the specimen, relative humidity and temperature of the environment, method of curing, degree of hydration, and time.

Concrete under stress will deform elastically. Sustained stress will result in additional deformation called creep.

2.2.3 Watertightness

Where concrete is exposed to weather or in water-retaining structures, it should be watertight. To achieve this impermeability, the paste itself must be watertight and the concrete must be free from cracks and honeycombing. The factors which determine the watertightness of concrete are low w/c ratio, length of curing period, and adequate consolidation.

2.2.4 Durability

The durability of concrete is defined as the ability to resist weathering action, chemical attack, abrasion or process of deterioration caused by nature or man. Durable concrete will retain its original form, quality and serviceability if exposed to the environment.

There are different types of aggression to concrete:

- Freezing and thawing (and deicing chemicals)
- Different types of chemical attack (industrial and natural)
- Abrasion and erosion
- Sea water
- Fire
- Low temperatures
- Nuclear radiation
- Natural and man-caused disasters (earthquakes, hurricanes, explosions, etc.)

From the material point of view, the overall durability of concrete is mostly a function of the cement paste and aggregate properties. Both of these materials must be of adequate quality to ensure acceptable performance, particularly if the concrete will be exposed to severe climatic conditions or different chemical attacks.

> As in a kitchen, where the quality of the ingredients used in a recipe is of much concern to a cook, but utmost importance is to be given to the ability to prepare the meal as it should to really make it of satisfaction to everybody, also in concrete adequate concreting, curing and structure design are, of course, more important factors than the ingredients themselves. Any high quality material will fail in a poor concrete. The right way to influence durability is to produce well designed, properly mixed, placed and compacted concrete. High strength, low porosity, good watertightness yield excellent durability.

3. STEPS IN CONCRETING

The potential qualities of concrete will only be realized if the entire concreting process is carried out properly. The manufacture of concrete comprises:

- Selection of materials
- Proportioning of materials (mix design)
- Mixing of concrete
- Transporting and placing of mix
- Compaction in place
- Curing, prevention of drying out
- Removal of formwork
- Quality control and testing

Quality of concrete depends on the following elements:

Table 1 Elements of Quality Concrete

STRENGTH

Quality paste
- proper cement and water content
- appropriate cement type

Quality aggregate
- sound particle
- suitable grading and particle shape

Quality processing
- proper proportioning
- efficient mixing
- sufficient vibration
- adequate curing

ECONOMY

Effective use of materials
- large maximum size aggregate
- proper aggregate grading
- proper cement content
- accurate yield
- proper slump

Ease of handling
- workable mix
- homogeneous concrete
- adequate vibration

Effective operation
- dependable equipment
- effective methods, plant layout and organization
- automatic control

DURABILITY

Resistance to weathering	**Resistance to wear-mechanical abrasion**
- freezing and thawing	- wear-resistant aggregate
- wetting and drying	- proper cement and water content
- temperature variations	- high strength
- suitable aggregate (well graded, structurally stable, large max. size)	- adequate curing
- optimum entrained air	- dense concrete
- proper cement and water content	- special surface finish
- adequate consistency	**Resistance to adverse chemical reactions**
- homogeneous concrete, workable mix, thorough mixing, proper handling, sufficient compacting	- proper cement type and content
- adequate curing, favorable temperature, min. loss of moisture	- homogeneous concrete
	- adequate curing
	- stable aggregate
	- suitable admixtures

4. VERSATILITY OF CONCRETE

Concrete is the most widely used building material in the world today. We find concrete in all kind of industrial, public and residential buildings, in underground structures, in transportation structuressuch as railroads, bridges, pavements and tunnels, in water and sewage treatment systems, power and offshore stations, dams, a.s.o.

The world production of concrete lies around 2 tons/year per every human being. The reasons for the wide usage of concrete are not difficult to find -

- the raw materials are in plentiful supply and available almost everywhere
- energy requirement for production is low
- costs are little if compared to other building materials
- a wide range of production and application technologies is available
- its great versatility covers a wide range of performance requirements.

Concrete competes with all major building materials - timber, steel, aluminium, asphalt, rock, plastic, glass, bricks, ceramics. Will concrete still have such a predominant role in the future? Is this predominance assured for the years to come? In the following Table 1 a comparison between concrete and its main competitive materials is reported.

Table 1 Position of concrete versus competitive materials

Application	Main competitive material	Position of concrete
Buildings, buildings frame	steel, timber	strong
Roads	asphalt, soil	weak
Bridges	steel, timber	strong
Dams	soil	strong
Partition walls	bricks, gypsum	weak
Pipelines	steel, plastics	balanced
Roofs	tiles, steel	weak
Tunnels	steel, natural stone	strong
Skyscrapers	steel	growing
Offshore structures	steel	strong
Foundations	masonry	strong
Sanitary structures	plastics, ceramics	balanced
Hazardous wastes treatment	steel	strong

In the following Table 2 a list of the various types of concrete and the different production methods is compiled.

Table 2 Types of concrete and production methods

Concrete types	
Plain	Repair mortar
Reinforced	Repair concrete
Prestressed	Flowing fill
Lightweight	Heat resistant
High performance	Chemical resistant
Fibre-reinforced	Coloured
Mass	Architectural
Mortars	

Production methods	
Ready-mixed	Pumped
Precast	Slipforming
Site-mixed	Underwater
Shotcrete	Vacuum
Roller compacted	Autoclaved
Steam cured	

History proves that no single human development remains predominant forever. However, the raw material reserves for making concrete are assured for many years to come and it is unlikely that some other material will take over in the foreseeable medium to long term.

Moreover the full potential of concrete as a structural material has not yet been realised; its obvious drawbacks such as low ductility, low tensile strength and low durability in some harsh environments are a challenge to concrete technologists to find suitable solutions.

Its capacity to absorb recycled materials and solve the problem raised by the concern of excessive CO_2 production will increase his competiotivity against other building materials.

For these and many other reasons, we firmly believe that concrete will keep its predominant role even in the 21st century.

5. CONCRETE TERMINOLOGY

In the following, a list of the most commonly used terms in concrete technology is compiled.

- Fresh concrete - concrete after mixing; it is still workable and can be transported on site and poured into the mould.
- „Green" concrete - concrete which, after being placed and compacted, has set but only hardened to a limited extent.
- „Young" concrete - concrete in an intermediate stage between „green" and hardened concrete; the material properties of young concrete change rapidly (for example, the strength increases exponentially) and are already similar to those of hardened concrete.
- Hardened concrete - artificial stone which after hydration of the cement with water has reached the properties required for a specific type of structure.
- Mortar - a mixture of cement paste and sand (maximum grain size 5 mm).
- Bleeding - autogenous flow of mixing water within, or its discharge from, newly placed concrete or mortar caused by the settling of solid materials in the mass.
- Curing - maintaining moisture and temperature in „green" and „young" concrete during a specific period to assure satisfactory hydration and proper hardening of concrete.
- Water/cement ratio - the ratio of cement to aggregate by weight.
- Normal weight concrete - concrete having a unit weight in the order of 2000 to 2800 kg/m^3 made with aggregates of normal weight.

- Lightweight concrete - concrete having a substantially lower unit weight (max. 2000 kg/m^3) than that made from gravel or crushed stone.
- Heavyweight concrete - concrete with exceptionally high unit weight (min. 2800 kg/m^3) usually made with heavyweight aggregates (possible application: radiation shields).
- In situ (cast-in-place) concrete - placed directly in the structure.
- Precast concrete - concrete cast in a place (e.g. mould at the factory) other than the structure.
- Ready-mixed concrete - concrete in fresh and unhardened state for delivery to the purchaser.
- Lean concrete - concrete of low cement content.
- Rich concrete - concrete of high cement content.
- Plain concrete - concrete without reinforcement.
- Reinforced concrete - concrete containing steel reinforcement and designed on the assumption that the two materials act together in resisting forces.
- Reinforcement - metal bars, wires or other slender members which are embedded in concrete in such a manner that the metal and the concrete act together in resisting forces.
- Prestressed concrete - concrete into which internal stresses of such magnitude and distribution are introduced that the tensile stresses resulting from the service loads are counteracted to a desired degree.
- Admixture - ingredient of concrete other than water, aggregates and cement, added just before or during mixing.

6. LITERATURE

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7. REVIEWING QUESTIONS

1) What is concrete made of?
2) Explain the functions of the concrete constituents.
3) What is the composition of paste?
4) Explain the water/cement ratio and its influence upon the properties of concrete.
5) Name the most important properties of concrete.
6) Name the three stages of the concrete development.
7) Name the steps in concreting.
8) Explain the difference between concrete and mortar.